RESEARCH DEPARTMENT

Pulse sound:

Suppression of vestigial sideband at 625 - line v.h.f. transmitters

RESEARCH REPORT No. EL - 7

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THE BRITISH BROADCASTING CORPORATION
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RESEARCH DEPARTMENT

PULSE SOUND : SUPPRESSION OF VESTIGIAL SIDEBAND AT 625-LINE V.H.F. TRANSMITTERS

Research Report No. EL-7
UDC 621.397.238 1967/30

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SUMMARY

If the 405-line television services in Bands I and III were re-engineered for 625-line working whilst maintaining substantially full coverage of the country, it would be necessary to use a closer channel spacing than the 8 MHz spacing available in the u.h.f. bands. The use of pulse sound effects some of the necessary economy in bandwidth, but for a channel spacing of less than 7 MHz and a minimum reduction in video-frequency bandwidth, it would be necessary to reduce the bandwidth of the vestigial sideband with a consequent increase in distortion of the transmitted signal. In this report it is shown that the resulting picture impairment, caused by the transmitter vestigial-sideband filter, can be reduced to acceptable proportions by the use of video-frequency pre-correction at the transmitter. In the region of the synchronizing pulses, the action of a video-frequency pre-correction network may be modified by non-linearity in the transmitter. It is unlikely, however, that under these conditions, the increase in distortion of the synchronizing pulses would be significant.

1. INTRODUCTION

The pulse-sound method of transmitting the sound content of a television programme[1] provides a substantial reduction in the bandwidth of the radio-frequency signal by using position-modulated pulses inserted in the line-blanking period of the video waveform. The pulse-sound system therefore offers a possible method of re-engineering the v.h.f. bands for 625-line working with a channel spacing of less than 8 MHz* (the spacing used in the u.h.f. band). If pulse-sound were used, it would, in fact, be possible to accommodate a 625-line colour service in the existing 5 MHz channels of the v.h.f. bands, but it would be necessary to use a colour sub-carrier frequency in the region of 3·58 MHz and to accept some loss of resolution. In order, therefore, to provide for the preferred colour sub-carrier frequency of 4·43 MHz, and to avoid undue loss of resolution, consideration has been given to coverage plans involving channel spacings of 6 MHz and above. If a channel spacing of 6·75 MHz or above were used, it would be possible to transmit the full 5·5 MHz video bandwidth of the 625-line television system and to use a vestige bandwidth** of 1·25 MHz. For smaller channel spacings, however, it would be necessary to reduce the vestige bandwidth, and for a channel spacing of 6 MHz, it would need to be restricted to 0·75 MHz. The vestigial sideband (v.s.b.) filter at the transmitter would then need to provide a more effective suppression of the unwanted sideband than is the case in the u.h.f. band where a 1·25 MHz vestige bandwidth is used.

In this report the distortion resulting from the use of a transmitter filter and its pre-correction at video frequency are investigated. Three video bandwidth/vestige bandwidth configurations are considered, namely:

Case 1	4·25 MHz video bandwidth with a 0·75 MHz vestige bandwidth
Case 2	5·0 MHz video bandwidth with a 0·75 MHz vestige bandwidth
Case 3	5·5 MHz video bandwidth with a 1·25 MHz vestige bandwidth

Modification of the video-frequency pre-correction, taking into account non-linearity in the transmitter characteristic at the levels of modulation corresponding to the synchronizing pulses is also considered. The investigation was made theoretically using a computer programme and assumes negative modulation of the transmitter.

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* The use of an 8 MHz channel spacing in Bands I and III would reduce the number of channels available from 13 to 8 and this loss of v.h.f. channels would have to be made good by the use of a number of u.h.f. channels. The allocation of an undue number of u.h.f. channels would be uneconomic and would also restrict future expansion in the u.h.f. band. It is therefore important to provide the maximum possible number of v.h.f. 625-line channels by use of the minimum possible channel spacing.

** For convenience, the bandwidth of the vestigial sideband will be referred to as the vestige bandwidth.

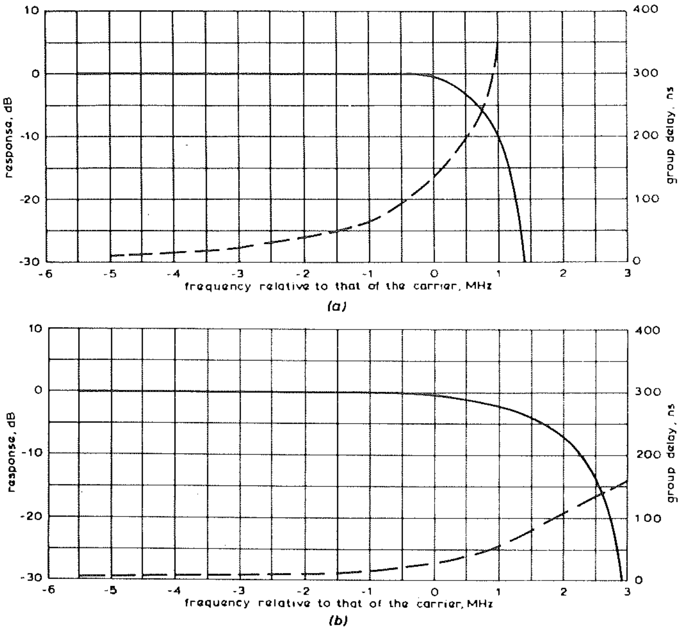

Fig. 1 - Response/frequency and group-delay/frequency characteristics of transmitter v.s.b. filters

(*a*) Transmitter filter suitable for 0·75 MHz vestige bandwidth
(*b*) Transmitter filter suitable for 1·25 MHz vestige bandwidth
——— response ——— group-delay

2. VIDEO-FREQUENCY PRE-CORRECTION

The response/frequency and group-delay/frequency characteristics of two transmitter filters[*] suitable for use with a pulse-sound system are shown in Fig. 1(*a*) and Fig. 1(*b*). The figures are drawn as if the main sidebands are lower than the carrier frequency, but the reverse could just as well be the case.

The characteristics shown in Fig. 1(*a*) are suitable for a 0·75 MHz vestige bandwidth whilst those shown in Fig. 1(*b*) are for a 1·25 MHz vestige bandwidth. The response/frequency characteristics of the filters assume channel spacings of between 5 MHz and 6·75 MHz (the minimum and maximum likely to be used). The shape of the characteristic in the region immediately above the vision carrier frequency is controlled by the need to protect the colour sub-carrier of the upper adjacent channel. The wider the channel spacing the wider the frequency spacing of the colour sub-carrier of the upper adjacent channel from the vision carrier, thus allowing a corresponding relaxation of the response/frequency characteristic. The response/frequency and group-delay/frequency characteristics shown in Fig. 1(*a*) can be regarded as representing the worst case likely to occur in practice.

When considering the distortion caused by frequency-dependent non-uniformity in the response and group-delay characteristics of the transmitter filter, it is convenient to determine the equivalent video-frequency characteristics. Since a vestigial sideband system is used, however, there is no precise relationship between the radio-frequency and video-frequency response/frequency and group-delay/frequency characteristics. However, it is shown in the Appendix that, to a reasonable approximation, the presence of the transmitter filter will result in a significant variation in the equivalent video group-delay/frequency characteristic but in little variation of the response/frequency characteristic. Thus a video-frequency network which compensates for the distortion introduced by the transmitter filter must introduce a change of group-delay with frequency but need not introduce a change of amplitude. It is further shown in the Appendix that this video-frequency pre-correction is substantially independent of the receiver v.s.b. characteristic.

In order to determine the picture impairment which would result from the use at the transmitter of a filter with the characteristics of Figs. 1(*a*) or 1(*b*), the computer programme was used to determine the routine "K" rating[2,3] of the three cases being considered. The programme was designed to determine the response of the transmission chain shown in Fig. 2 to a "2T" pulse-and-bar signal and it should be noted that an ideal receiver[**] with the appropriate vestige bandwidth was assumed for each case.

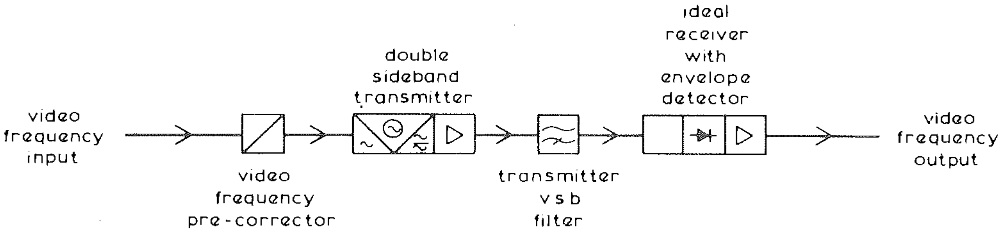

Fig. 2 - Transmitter chain assumed in computer programme

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[*] The two filters have not the same attenuation at the nominal cut-off frequencies of the vestigial sideband. This is due to the fact that they are representative of actual transmitter filters that have been used on 405 and 625-line transmissions.

[**] The receiver had a phase-corrected characteristic and a response/frequency characteristic of unity from vision-carrier frequency minus the video bandwidth to vision-carrier frequency minus the vestige bandwidth. The response (as a percentage of maximum) decreased linearly from 100% to zero over the range: vision-carrier frequency minus the vestige bandwidth to vision-carrier frequency plus the vestige bandwidth.

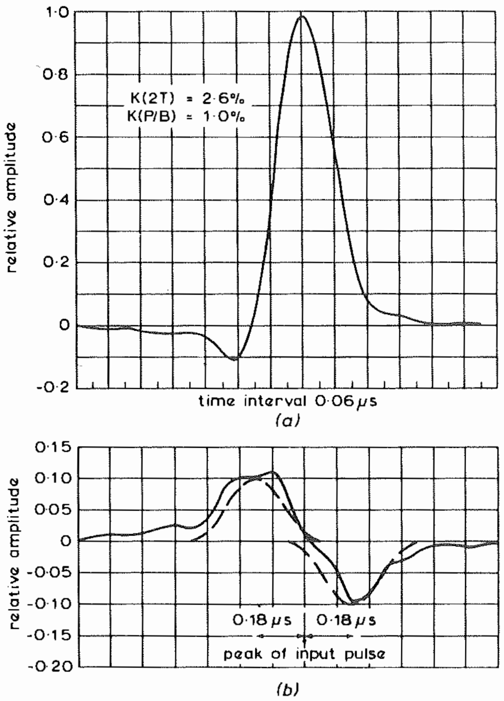

Fig. 3 - Distortion due to transmitter v.s.b. filter Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)

(*a*) Response of transmission chain without video-frequency pre-correction
(*b*) Derivation of video-frequency pre-correction signal

——— required correction term
— — pulses used to synthesize correction term

The calculated responses to a 2T pulse, without video-frequency pre-correction, are shown in Figs. 3(*a*), 4(*a*) and 5(*a*), together with the pulse-and-bar "K" ratings. Fig. 3(*a*) is the response of Case 1(4·25 MHz video bandwidth, 0·75 MHz vestige bandwidth); Fig. 4(*a*) is the response of Case 2 (5·0 MHz video bandwidth, 0·75 MHz vestige bandwidth) and Fig. 5(*a*) the response of Case 3 (5·5 MHz video bandwidth, 1·25 MHz vestige bandwidth). In the calculation, a low level of modulation was assumed so that the effects of quadrature distortion are virtually absent and in each case the routine "K" rating (the largest of the "K" ratings given by Figs. 3(*a*), 4(*a*) and 5(*a*) respectively) is due to the non-uniform group-delay characteristic of the transmitter filter (see Appendix). Except for Case 3 the rating cannot be regarded as acceptable since a routine "K" rating for the transmitter not exceeding 1·5% is considered desirable[3].

The distorted output pulses shown in Figs. 3(*a*), 4(*a*) and 5(*a*) can be regarded as comprising an undistorted 2T pulse with an added term representing the distortion introduced by the transmitter filter. The required video-frequency correction signal may therefore be obtained by subtracting the distorted 2T pulse from an undistorted 2T pulse. Figs. 3(*b*), 4(*b*) and 5(*b*) show the required correction terms, for Case 1, Case 2 and Case 3 respectively, obtained by this means and inspection shows that each can be synthesized approximately by two 2T pulses of suitable amplitude and position; this is illustrated by the dashed-line curves in Figs. 3(*b*), 4(*b*) and 5(*b*). One of these pulses has the same polarity as, and leads, the input 2T pulse and the other, of opposite polarity, lags the input 2T pulse, the two pulses additionally being symmetrically disposed about the input 2T pulse. The magnitude of both these pulses is about 10% to 15% of the magnitude of the input 2T pulse.

It was therefore possible to reduce the distortion due to the transmitter filters by adding, to the input video-frequency signal, the appropriate video-frequency pre-correction signals shown in Figs. 3(*b*), 4(*b*) and 5(*b*). The responses of the systems after the inclusion of a video-frequency pre-correction network designed to generate the correction signals shown in Figs. 3(*b*), 4(*b*) and 5(*b*) are shown in Figs. 6, 7 and 8 (Cases 1, 2 and 3 respectively) together with the pulse-and-bar "K" ratings. It will be seen that the addition of this relatively simple form of video-frequency pre-correction has improved the routine "K" ratings (1·7%, 2·0% and 1·4% given by Figs. 6, 7 and 8 respectively) and these figures are sufficiently near the accepted

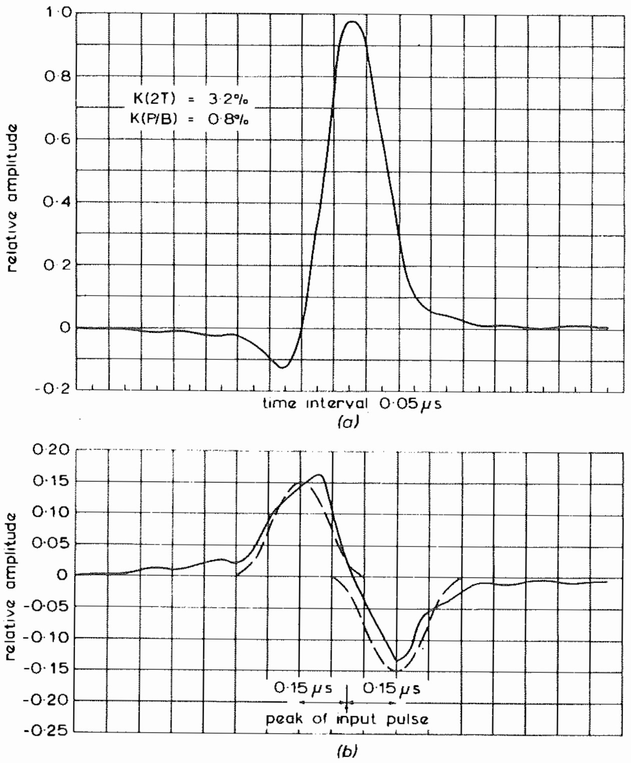

Fig. 4 - Distortion due to transmitter v.s.b. filter Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)

(*a*) Response of transmitter chain without video-frequency pre-correction
(*b*) Derivation of video-frequency pre-correction signal

——— required correction term
— — pulses used to synthesize correction term

maximum value to be regarded as satisfactory. However, the video-frequency pre-correction circuit assumed in the calculation is relatively simple and a somewhat more complex network could give a further improvement.

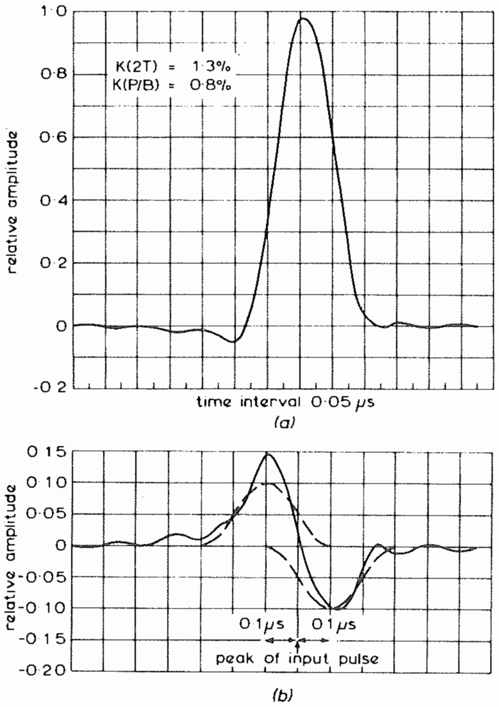

Fig. 5 - Distortion due to transmitter v.s.b. filter Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

(*a*) Response of transmitter chain without video-frequency pre-correction
(*b*) Derivation of video-frequency pre-correction signal

——— required correction term
— — pulses used to synthesize correction term

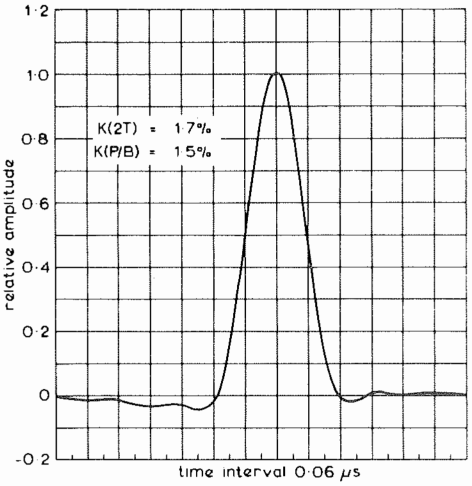

Fig. 6 - Response of transmitter chain with video-frequency pre-correction Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)

3. HIGH LEVELS OF MODULATION

In Section 2, it has been shown that video-frequency pre-correction can compensate for the distortion introduced by the non-uniform group-delay/frequency characteristic of the transmitter filter. The calculations assumed, however, a low level of modulation so that quadrature distortion was virtually absent.

It is of interest to assess the effect of video-frequency pre-correction when high levels of modulation are used and it was decided to use the computer programme for this purpose. The sine-squared pulse-and-bar signal is not suitable for the assessment of distortion under such conditions and a step waveform is more appropriate.

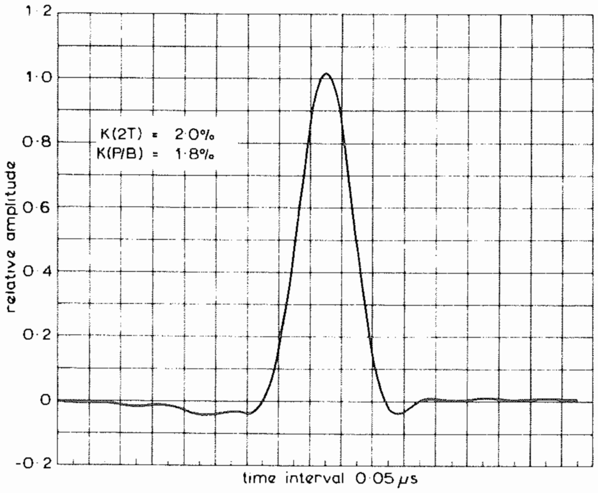

Fig. 7 - Response of transmitter chain with video-frequency pre-correction Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)

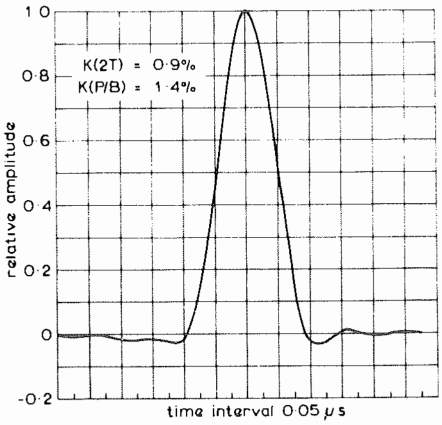

Fig. 8 - Response of transmitter chain with video-frequency pre-correction Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

The test waveforms are shown in Figs. 9(*a*), 9(*b*) and 9(*c*) and consist in each case of the leading edge of a "sine-squared" black-to-white step transition with band limitation appropriate to Case 1, Case 2 and Case 3 respectively.

Figs. 10(*a*), 10(*b*) and 10(*c*) show, for each case, the resulting step transitions that would be obtained at the receiver output without the transmitter v.s.b. filter shown in Fig. 2 or the video-frequency pre-corrector. The waveforms of Figs. 10(*a*), 10(*b*) and 10(*c*) thus represent the limiting condition in which no distortion is introduced by the transmitter and only quadrature distortion due to the receiver v.s.b. characteristic occurs.

Figs. 11(*a*), 11(*b*) and 11(*c*) (Case 1, Case 2 and Case 3 respectively) show the increase of distortion caused when the v.s.b. filter is inserted at the output of the transmitter* and Figs. 12(*a*), 12(*b*) and 12(*c*) show the improvements obtained when video-frequency pre-correction is inserted.

* It will be noted that, in this condition, the amplitudes of the step transitions are slightly less than those shown in Figs. 10(*a*), 10(*b*) and 10(*c*). This is due to the fact that responses of the transmitter filters (shown in Fig. 1) introduce a small attenuation in the region of the carrier frequency.

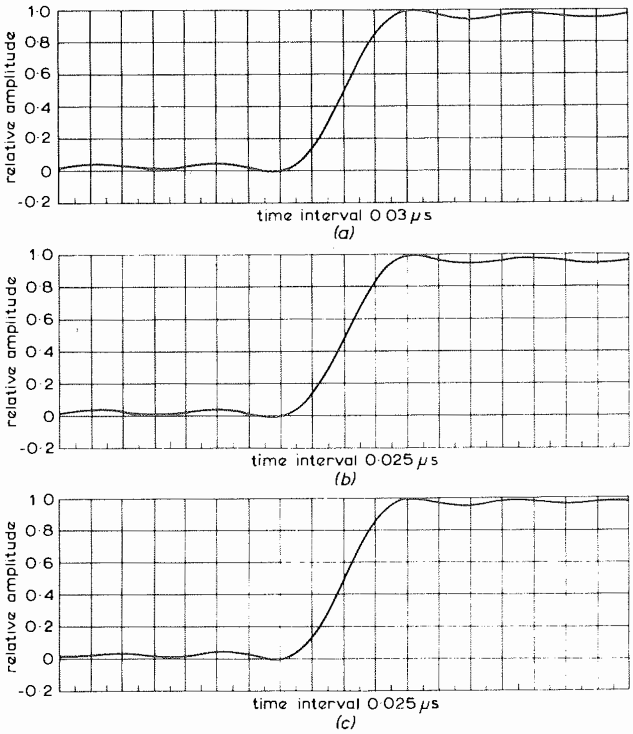

Fig. 9 - Input step-transitions assumed for high-level-modulation assessments

(*a*) Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)
(*b*) Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)
(*c*) Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

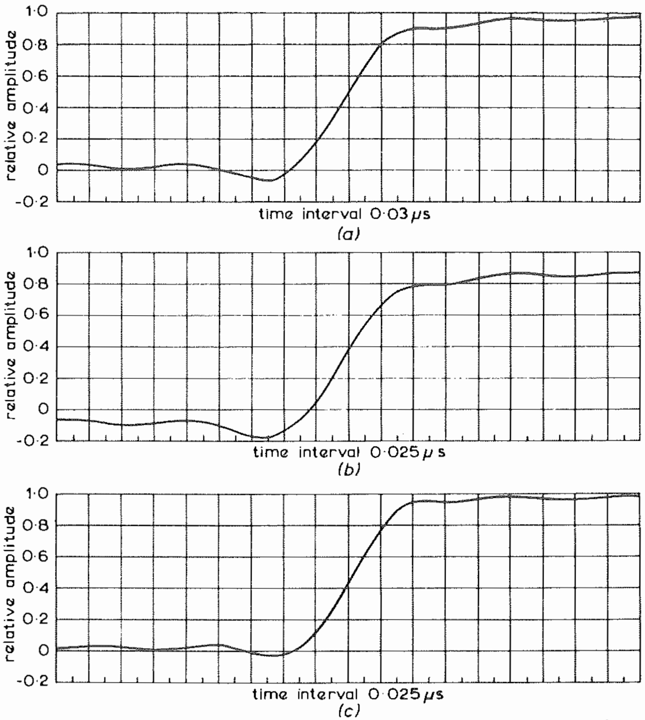

Fig. 10 - Output step-transitions without using transmitter v.s.b. filters

(*a*) Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)
(*b*) Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)
(*c*) Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

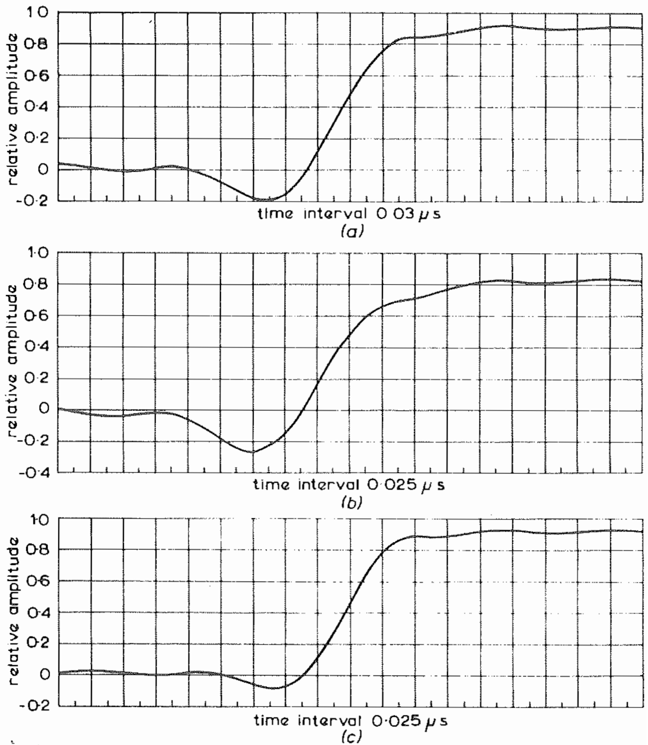

Fig. 11 - Output step-transitions using transmitter v.s.b. filters

(*a*) Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)
(*b*) Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)
(*c*) Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

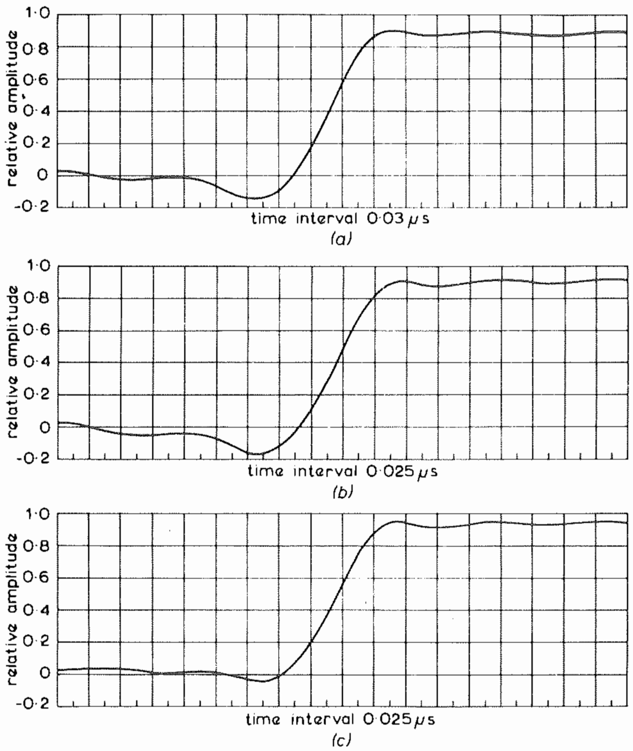

Fig. 12 - Output step-transitions using transmitter v.s.b. filters and video-frequency pre-correction

(*a*) Case 1 : (video bandwidth 4·25 MHz, vestige bandwidth 0·75 MHz)
(*b*) Case 2 : (video bandwidth 5·0 MHz, vestige bandwidth 0·75 MHz)
(*c*) Case 3 : (video bandwidth 5·5 MHz, vestige bandwidth 1·25 MHz)

4. THE EFFECT OF TRANSMITTER NON-LINEARITY

Transmitters are designed to be linear only over the range between the extremes of modulation occupied by the picture signal. For example, a transmitter designed for colour operation on the British 625-line system (Standard I) will have a substantially linear characteristic over the range from approximately zero carrier amplitude to approximately 90% carrier amplitude (peak of the colour burst). However, at carrier levels above 90%, in the region of the tips of the synchronizing pulses, the transmitter characteristic may be non-linear. Thus, so far as the synchronizing pulses are concerned, the non-linearity of the transmitter may tend to remove any advantage obtained from video-frequency pre-correction. This is because overshoots produced on the synchronizing pulses by the corrector (which are necessary to remove the distortion introduced by the transmitter filter) may be suppressed.

It can therefore be said that video-frequency pre-correction may not remove the distortion of the synchronizing pulses which results from the presence of the transmitter v.s.b. filter. It is therefore necessary to assess whether this distortion must be regarded as serious from the point of view of the operation of domestic receivers or whether it can be ignored. Now calculations show that the presence of the transmitter filter will produce over- and undershoots of about 3% on the synchronizing pulses. This amount of distortion is considered to be acceptable since it is small compared with the effects of echoes commonly occurring during propagation and is also small compared with the distortion which occurs in many domestic receivers.

5. EFFECT OF RECEIVER CHARACTERISTICS

Although this report is concerned with the distortion caused by the presence of the transmitter v.s.b. filter, it is appropriate to make brief mention of the distortion that would arise in the receiver if a system with 0·75 MHz vestige were used. The results given in Sections 2, 3 and 4 assumed an ideal v.s.b. receiver characteristic and do not therefore include distortion arising in the receiver other than quadrature distortion.

The use in the receiver of the relatively small vestige bandwidth of 0·75 MHz will result in a significant change of group-delay as a function of frequency. This group-delay change will give rise to distortion which could, in theory, be compensated by additional video-frequency correction at the transmitter. This procedure, however, presents some difficulty due to the wide variation in the characteristics of domestic receivers and it is unlikely to prove practicable: it follows, therefore, that a 625-line pulse-sound system using 6 MHz channels will be subject to distortions in the receiver greater than those occurring with the 625-line Standard I system used in the u.h.f. bands. It must, however, be noted that the distortion arising in a pulse-sound receiver with major sideband bandwidth of 5·0 MHz and a 0·75 MHz vestige bandwidth will be no greater than that experienced in continental European countries using Standard G and, moreover, no greater than that occurring in many current designs of British 625-line domestic receivers. If it were decided that the distortion resulting from the use of a vestige bandwidth of 0·75 MHz would be unacceptable, two methods of improving picture quality would be possible. On the one hand, an increase of channel width of 0·5 MHz would provide sufficient space for a vestige of 1 MHz to 1·25 MHz; thus if a channel width of 6·5 MHz or more were used, the distortion arising in the receiver would not be significantly greater than that occurring in the 625-line Standard I system having an 8 MHz channel width. On the other hand, Recommendation 266 of the Xth Plenary Assembly of the CCIR at Geneva in 1963 could be implemented. Under the heading "Phase Correction of Television Transmitters Necessitated by the Use of Vestigial-Sideband Transmission", it states that the television picture transmitter may also introduce a correction to compensate for linear distortions arising in the receiver, but this correction shall not exceed one half of that necessary to compensate a receiver using normal minimum-phase-shift networks and with an amplitude characteristic corresponsing to the television standard concerned and also that this pre-correction applies only to frequencies between zero and up to approximately half the video bandwidth.

6. CONCLUSIONS

If a pulse-sound television system were used in the v.h.f. bands with a channel spacing of 6 MHz, it would be necessary to use a vestige bandwidth of 0·75 MHz and a correspondingly severe attenuation of the vestigial sideband at the transmitter. The investigation described in this report indicates that under these conditions, and assuming negative modulation, the following conclusions may be drawn:

(i) The transmitter filter necessary to suppress the vestigial sideband would cause unacceptable distortion mainly due to its non-uniform group-delay characteristic. This distortion could, however, be reduced to an acceptable level by the use of a relatively simple video-frequency pre-correction circuit at the transmitter input.

(ii) The action of the video-frequency pre-correction circuit would be modified by the non-linear nature of the transmitter characteristic in the region of the synchronizing pulses. However, the resulting distortion of the synchronizing pulses would be unlikely to affect the operation of domestic receivers.

(iii) The use of a vestige bandwidth of 0·75 MHz would result in an increase in receiver distortion as compared with that occurring in the 625-line Standard I system used in the u.h.f. bands. However, the level of distortion would be similar to that occurring in continental European countries using Standard G and could in any case be reduced if a channel width of 6·5 MHz or more were used or if Recommendation 266 of the CCIR Xth Plenary Assembly, 1963, were implemented.

7. REFERENCES

1. Pulse Sound : A system of television sound broadcasting using pulses in the video waveform. BBC Research Department Report No. T-181, Serial No. 1966/73.

2. LEWIS, N.W. 1954. Waveform responses of television links. *Proc.Instn elect.Engrs.*, Part III, 1954, **101**, 72, pp. 258 - 269.

3. The specification of the radiated spectrum of 625-line vestigial sideband broadcast transmissions. BBC Research Department Report No. T-177, Serial No. 1963/59.

APPENDIX

Video-Frequency Correction of the Characteristic of the Transmitter V.S.B. Filter

Suppose that the response/frequency and phase/frequency characteristics of the transmitter v.s.b. filter are $R(x)$ and $\theta(x)$ respectively. The variable x is $\omega_1 - \omega_0$ where ω_1 is a sideband at radio frequency and ω_0 is the vision carrier frequency. Further, for convenience, at the vision carrier frequency, $R(0)$ is taken to be unity and $\theta(0)$ is taken to be zero.

If the transmitter is modulated with a video frequency ω, the radio-frequency signal, in complex form, will be:

$$e^{j\omega_0 t}[1 + \frac{m}{2}R(\omega)e^{j\omega t + j\theta(\omega)} + \frac{m}{2}R(-\omega)e^{j\omega t + j\theta(-\omega)}] \tag{1}$$

where m is the index of modulation

Suppose now, that the radio-frequency signal is demodulated in a v.s.b. receiver with a response/frequency characteristic $V(x)$ and phase/frequency characteristic $\phi(x)$. As in the case of the transmitter filter $V(0) = 1$ and $\phi(0) = 0$. The radio-frequency signal prior to the detector will therefore be:

$$e^{j\omega_0 t}[1 + \frac{m}{2}Ae^{j\omega t + jB} + \frac{m}{2}Ce^{-j\omega t + jD}] \tag{2}$$

where $A = V(\omega)\ R(\omega)$
$B = \theta(\omega) + \phi(\omega)$
$C = V(-\omega)\ R(-\omega)$
$D = \theta(-\omega) + \phi(-\omega)$

If the level of modulation is taken to be low, then $m \ll 1$ and the output of an envelope detector will be:

$$\frac{m}{2}e^{j\omega t}[Ae^{jB} + Ce^{-jD}] \tag{3}$$

At video frequencies around and above the vestige frequency (i.e. from approximately 0·75 MHz to approximately 5 MHz in the pulse-sound system) $V(-\omega)$ and hence C will be small and the term Ce^{-jD} can be ignored. The detector output will therefore have a substantially flat amplitude characteristic (since $V(\omega)$ and $R(\omega)$ will be substantially constant) and a group delay characteristic

$$\frac{d\theta(\omega)}{d\omega} + \frac{d\phi(\omega)}{d\omega}$$

At low frequencies $V(\omega)$, $R(\omega)$, $\theta(\omega)$ and $\phi(\omega)$ will be approximately equal to $V(-\omega)$, $R(-\omega)$, $\theta(-\omega)$ and $\phi(-\omega)$ respectively. Provided, therefore, that the receiver response at the vision carrier frequency is 6 dB below that at the higher video-frequencies, expression (3) becomes:

$$mV(\omega)R(\omega)e^{j[\omega t + \theta(\omega) + \phi(\omega)]} \qquad (4)$$

Thus, as in the case of the higher video-frequencies, the group-delay characteristic will be

$$\frac{d\theta(\omega)}{d\omega} + \frac{d\phi(\omega)}{d\omega}.$$

It will be seen, therefore, that two conclusions can be drawn from this analysis:

(a) The video response/frequency characteristic will correspond to that of the full transmitted sideband at low modulation frequencies and at modulating frequencies around and above the vestige frequency. Between these points, however, there will be a small region in which the video-frequency characteristic deviates from the main sideband characteristic.

(b) The video-frequency group-delay/frequency characteristic resulting from the transmitter and receiver v.s.b. characteristics approximates to the sum of the transmitter and receiver radio-frequency group-delay/frequency characteristics. Thus distortion due to the radio-frequency group-delay/frequency characteristic of the transmitter filter can, to a large extent, be regarded as independent of distortion due to the radio-frequency group-delay/frequency characteristic of the receiver. It follows that it is possible to use video-frequency pre-correction of the group-delay/frequency characteristic of the transmitter filter and that this pre-correction will be largely independent of the type of receiver used.

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